

Behaviour of Long Pile in Slope Subjected to Inclined Load

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ABSTRACT: Structures like, bridge abutment on steep river slope, open type berthing structure, electric / telephone poles on high way/ railway embankment and approach to water intake tower in river /sea are constructed in sloping ground and this structures are subjected to lateral load due to the lateral soil movement of unstable slope. Lateral movement of these unstable slope results in large lateral force on pile supported structures. In order to understand such type of behaviour, an experimental investigation is necessary. Due to such lateral loads and the no availability of good construction sites, engineers are often required to place footings at crest or near slopes. Therefore, the footings in the field generally face large lateral forces and lateral soil movement. These structures may be subjected to large lateral loads, such as violent winds and earthquakes. Widely used types of foundations for these structures are pier foundations, subjected to lateral loads is similar to that of a short rigid pile, because both elements seem to fail by rotation developing passive resistance on opposite faces above and below the rotation point. This paper describes the results of several experimental studies performed on laterally loaded and load inclined on long pile located near slopes. Initially, in this paper, the results of tests of single pile subjected to lateral loading, in homogeneous sand with (1V:2H) slope and load with inclination of 15° and 30° were carried out.

An extensive program of laboratory model tests was undertaken to study the effect of slope and loading direction on laterally loaded pile in cohesionless soil. The paper includes studies of the effect of distance from the crest of the slope, direction of loading (angle of inclination with respect to horizontal), soil properties. The pile lateral capacity in sloping ground was compared with loading at different angle of inclinations. From the experimental investigation, it is observed that when piles installed away from the crest of the slope at a distance of 5 times the pile diameter, the influence of slope in the lateral-load capacity is almost negligible over inclined loading of 30°.

KEYWORDS: Lateral loading capacity, Lateral deflection, Pile, Slope

I. INTRODUCTION

The civil engineering developments are continuing all over the world. Infinite land on the earth has becoming finite for the construction. Structures like, bridge abutment on steep river slope, open type berthing structure, electric / telephone poles on high way/ railway embankment and approach to water intake tower in river /sea are constructed in sloping ground and this structures are subjected to lateral load due to the lateral soil movement of unstable slope. Lateral movement of these unstable slope results in large lateral force on pile supported structures. In order to understand such type of behaviour, an experimental investigation is necessary. Due to such lateral loads and the no availability of good construction sites, engineers are often required to place footings at crest or near slopes. Therefore, the footings in the field generally face large lateral forces and lateral soil movement.

The general scenario is to design the footings on a crest of a slope. The effect of lateral forces and lateral soil movement is not considered while designing the footings placed away from the crest. The various parameters of footing have the varying lateral resistances. Thus, the effect of the various varying parameters which will have the effect on the lateral resistance capacity and lateral movement are studied under the behaviour of single pile in slope subjected to inclined load.

Deep foundations, including driven piles, are used to support vertical loads of structures and lateral forces. Typical structures subjected to lateral loads include bridge abutments, transmission tower, sand offshore platforms. Traffic,

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wind, wave, and seismic forces are common types of lateral loads subjected to pile foundations. These lateral forces are sometimes much greater than the weight of the structure itself. Therefore, the foundation systems must be designed to resist both axial forces and lateral forces. Generally, vertical piles resist lateral loads or moments by deflecting laterally until the necessary reaction in the surrounding soil is mobilized. The magnitude of resisting force increases as the lateral deflection increases until it reaches an ultimate value.

In many practical situations, structures subjected to lateral loading are located near excavated slopes or embankments. Bridge abutments, in most circumstances, are constructed on or near a slope crest to accommodate grade separations or geographical feature. The lateral behavior of such structures and pile foundations is different from those constructed on a level ground. Under lateral loads, the piles may induce slope failure, particularly at shallow depths, as well as may undergo severe reduction in its lateral capacity.

The main objective is to investigate and establish the relationship of the pile response and the location of pile relative to slope crest, and the embedded length of pile. Over the past several decades, the lateral capacities of piles have been the focus of many types of research. Multiple methods have been developed to model the soil-pile response when subjected to lateral forces. These methods have been developed from analytical solutions, laboratory models, and full scale tests.

II. RELATED WORK

Driven pile foundations are used to support a wide variety of structures. In many cases, lateral loads are often the critical factors considered in the design of foundations. To resist lateral loads vertical piles can be used. Engineers typically did not evaluate lateral loads on deep foundations until the early 1950s and designed foundation only to resist axial loads.

This literature review presents research conducted on lateral load testing and the effects of slope on lateral capacity on piles in cohesionless soils. An overview of the different methods and theories used in the analysis of the lateral capacity of piles in level (horizontal) ground and on the slopes are presented.

The work done by various authors is summarized as follows:

1. Reese *et al.* (1974)¹ conducted full scale tests on 24 inch diameter piles in clean fine to silty sands with a friction angle, $\phi=39^\circ$. The water table was above the ground surface during these tests. Static and cyclic lateral load tests were carried out on the test piles. A set of p-y curves and equations were developed based on the experimental results. According to Reese, two different wedge types can be distinguished, one for clay and one for sand.
2. The American Petroleum Institute (API)² suggested a model to develop p-y curves in cohesionless soils (api, 1987) based on the methods presented by Reese *et al.* (1974). The api model provides simplified calculation procedures and results in an ultimate lateral resistance of similar magnitude to Reese *et al.* (1974). The main modification compared to Reese *et al.* (1974) of the api model is the shape of the p-y curve before the ultimate resistance is reached, thus a change in the initial subgrade reaction. Similar to the empirical adjustment factor used by Reese *et al.* (1974), api applies three coefficients to the model which are functions of friction angle.
3. Gabr and Bordan (1990)³ examined lateral capacities of piers constructed in and near sloping ground. A model to estimate the ultimate soil resistance, p_u , is expressed by conducting a three-dimensional wedge equilibrium analysis. This model is then used to construct p-y curves for pier located in sloping ground. An assumption of this wedge model is that the pier is a rigid cylinder moving laterally in the soil. The pier is compressed laterally until a passive state is reached in the soil in front of the pier. The soil behind the pier is in an active condition. The pier is assumed to be frictionless and vertical displacements are neglected. The ultimate soil resistance is calculated by summation of the resisting forces along the side and bottom plains of the assumed failure wedge in a lateral direction. Gabr and Bordan (1990) conducted a parametric analysis on the presented wedge model, for a pile located on the crest of a slope with different friction angles and slope angles.
4. Mezazigh and Levacher (1998)⁴ conducted a program investigating slope effects on p-y curves. Centrifuge tests were carried out on scaled-piles driven into dry, fine sand. Each test pile was spun to 40 g in a test centrifuge. Multiple tests were performed in level ground conditions, and near two slopes with dimensions of 2h:1v and

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3h:2v. Piles were tested at distances between 0 and 12 d from the test slope where d represents pile diameter. Relative densities, d_r of 51% and 81% were used during this experiment to examine the effects of density in relation to slope and lateral capacities.

5. Reese *et al* (2006)⁵ presented a modified method of Reese *et al* (1974) to determine the ultimate lateral resistance of a single pile located on a slope loaded in the downslope direction. This method, is valid for slopes less steep than the friction angle of the cohesionless materials. The modifications in this equation assumed that only the passive wedge failure needed modification and the flow-around failure is not affect by a slope.
6. Mirzoyan (2007)⁶ carried out a near slope full-scale lateral load test in a cohesionless soil. The testing consisted of three lateral load tests on 12in diameter steel pipe piles located on the crest (0d) slope and three pile diameters (3d) behind the crest. A baseline tests was also conducted to in horizontal ground for comparison of results. Each pile was laterally loaded in partially saturated dense sand with a relative compaction of 95% and a friction angle of 39°. The 0d and 3d piles tests near a 30° slope.
7. Nimityongskul (2010)⁷ conducted a series of full scale tests at the test site of the oregon state university for his dissertation [3]. This included two tests in horizontal ground, four tests at a distance 8d, 4d, 2d and 0d from the crest of the slope, and one test in the slope at a distance -4d from the crest. The first soil layer, which was 10d thick, consisted of cohesive soil, in which a slope was excavated of 2:1 to a depth of 2.75m. This layer was underlain by alternating layers of sand and clay. The embedded length of the tested piles was 7.9m.

III. MATERIALS & PROPERTIES

The materials used for the project was Kanan sand and long pile is made up of mild steel.

3.1 Test Sand:

For the model tests, cohesionless, dry, clean and wash Kanan sand was used as the foundation material.

3.2 Model Pile

The model pile of size $L/D=20$ was fabricated by using mild steel material. The model pile was length of 20cm and 1 cm in diameter.

3.3 Experimental Set Up

The test tank size of 0.7m x0.4mx 0.5m deep was chosen to avoid any tank-wall effect on the lateral capacity of the piles. The lateral load was applied though a pulley arrangement. The pulley arrangements was fabricated such that the lateral loads could be applied in forward (toward sloping ground). The tests were conducted sloping ground, (1v:2h) with same (D_r) relative density. A single pile was tested on each model configuration at the crest of the slope, $b=2.5D$, 5D, 7.5D in the embankment, away from the slope. For all tests, the pile head was maintained as a free-headed condition.

3.4 Laboratory Tests

The various laboratory tests were performed to decide the different geotechnical and engineering properties of sand. The properties of sand used are as shown in Table 1.

Table1: Properties of Sand Used

Sr. No.	Properties	Values
1	Type of soil	Sandy soil
2	Specific gravity	2.57
2	γ_{max}	17.67 kN/m ³
3	γ_{min}	16.94 kN/m ³
4	Angle of internal friction, ϕ	27.5°

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5	Average grain size (D60)	1.10
6	Effective grain size (D10)	0.45
7	Coefficient of uniformity (Cu)	2.44
8	Coefficient of curvature (Cc)	1.03
9	I. S. Classification	Medium sand, SP grade

3.5 Laboratory Lateral Load Test

For the experimental investigations, the lateral load tests was conducted on sand and to evaluate the lateral load carrying capacity and lateral deflection. In the laboratory it was maintained by refilling the tank after each test by sand raining technique by funnel method to same density.

3.6 Laboratory Set-Up

Laboratory set-up consisted of a tank, a horizontal and inclined loading frame, a model footing, pulleys and dial gauges. Laboratory setup of test tank is shown in Fig.1



Fig. 1: Laboratory Setup of Test Tank

3.7 Test Tank

The test tank was made of 4 mm thick having internal dimensions 700mm ×400mm in plan and 500 mm high. The minimum tank size required to be 5 times the width or breadth of footing whichever was more. The bulging effect was counteracted by providing sufficient thick tank. 3-D view of laboratory test tank is shown in Fig.2

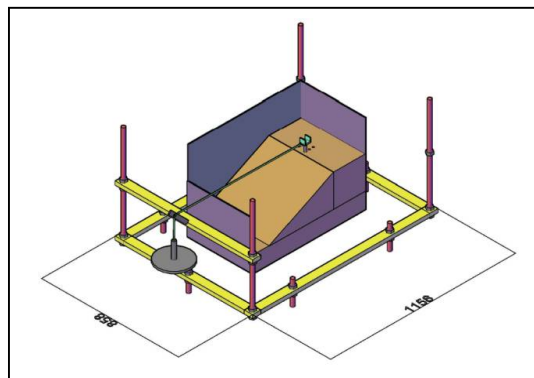


Fig. 2: 3D View of Test Tank

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3.8 Test Programme

An experimental program was carried out to evaluate the effects of lateral behaviour of a pile located near to the slope crest. Soil samples were constructed in layers by controlled pouring and tamping technique with the bed level and slope observed through the front glass wall. 400 mm in height model slopes was constructed with a minimum depth of sand below the base of the model pile of 100 mm $>(5D)$ to minimize the influence of tank base. The inner faces of the tank was marked at 50 mm intervals to facilitate accurate preparation of the sand bed in layers. On reaching the level of pile base, the pile will be placed on position and is held vertical using special clamp and a layer of sand is poured and tamped. Great care was given to level the slope face using special rulers so that the relative density of the top surface was not affected. Finally, the lateral load was applied incrementally until reaching failure. Each load increment was maintained constant until the pile lateral deflection had stabilized.

All tests were conducted with an artificially made slope of 1V:2H. The pile displacements was measured using two 50 mm travel dial gauges accurate to 0.01 mm placed at two different positions along the length of the pile above the soil surface. Pile rotations at the point of load application was calculated as the ratio of the difference of the two dial gauge readings to the vertical distance between the two measurement points. The details of parametric study are given in Table 2

Table 2: Details of Parametric Study

Sr. No.	Parameters	Details of parameter
1	No. Of piles	1
2	Location of pile	2.5D, 5D & 7.5D
3	Dia. Of pile	10mm
4	Length of pile	20D
5	Loading condition	Inclined
6	Slope	1v : 2h
7	Tank dimensions	0.7m X 0.4m X 0.5m
8	Roughness of pile	Rough
9	Inclination angle	0°, 15° & 30°

IV. RESULTS AND DISCUSSION

The load vs lateral deflection behaviour of model piled is determined by conducting a lateral load tests on short pile of $L/D=20$. The safe lateral load capacity of pile footing is decided with the help of IS 2911(1985). The experimental results that lateral load capacity increases as the distance of pile from slope crest.

The lateral test was conducted on 20 mm pile. The load and corresponding deflection was recorded. Fig.3 shows the load deflection curve for 10mm diameter pile, at distance of $b=2.5\text{cm}$, 5cm and 7.5cm for 0° .

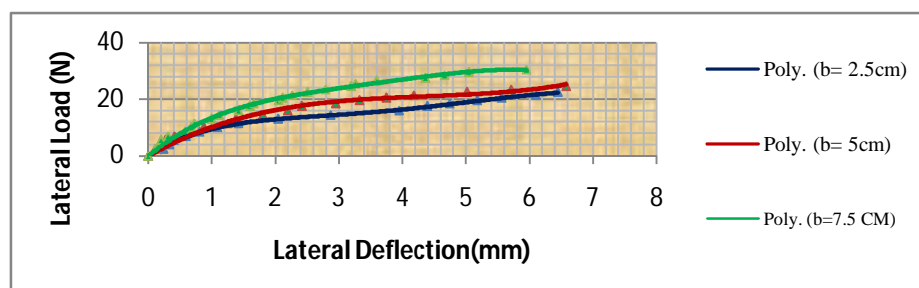


Figure 3: lateral load vs lateral deflection of long pile for 0° of inclination

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Fig.4 shows the load deflection curve for 10mm diameter pile, at distance of $b=2.5\text{cm}$, 5cm and 7.5cm for 15° inclinations (inclination with horizontal plane).

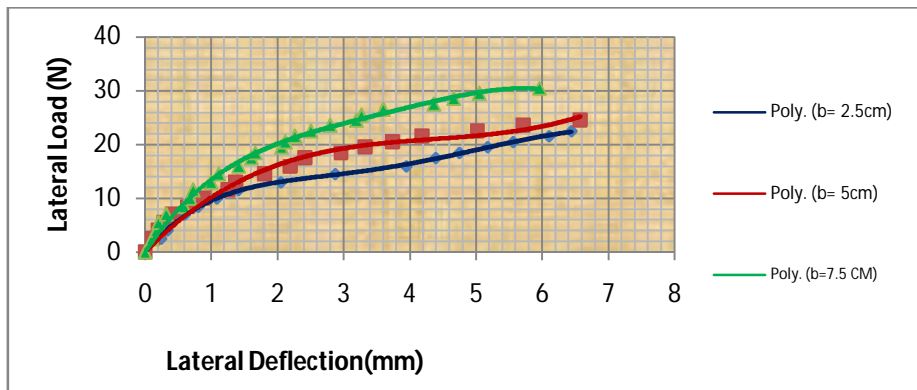


Figure 4: lateral load vs lateral deflection of long pile for 15° of inclination

Fig.5 shows the load deflection curve for 10mm diameter pile, at distance of $b=2.5\text{cm}$, 5cm and 7.5cm for 30° inclinations (inclination with horizontal plane).

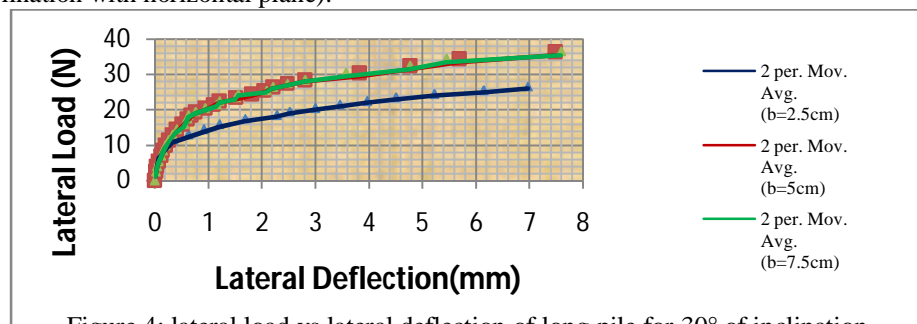


Figure 5: lateral load vs lateral deflection of long pile for 30° of inclination

The lateral safe load was decided from load at which 5mm deflection was occurred. The lateral safe load capacity was observed to be shown in Table 3. All the safe lateral loads are compared in the following table.

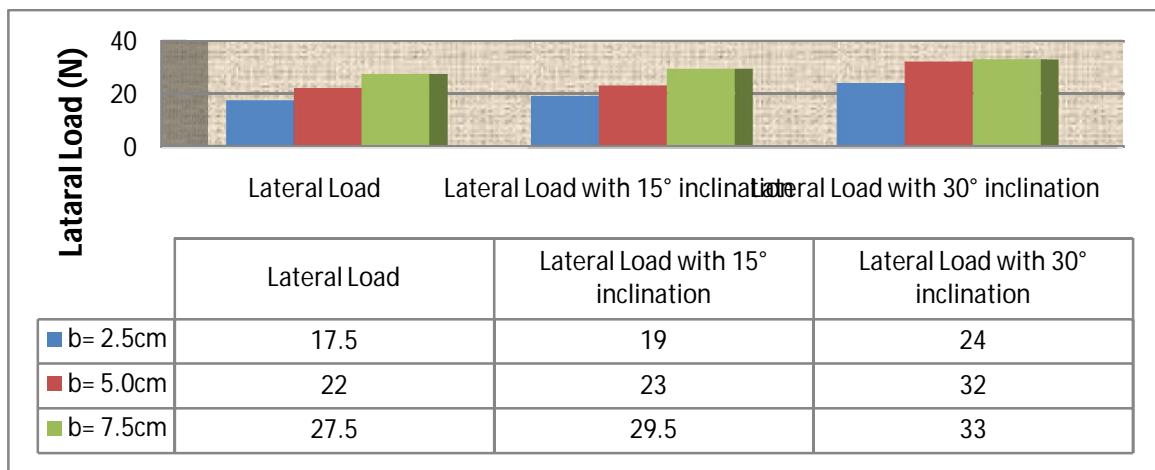


Table 3: Comparison of Safe Lateral Load(From Bar Chart Comparison)

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V. COCLUSION

The improvement in lateral capacity depends on the embedment depth, location of pile magnitude of force, and the direction of force. The improvement in lateral capacity is found to be more with lateral loading with more inclination. The improvement in lateral capacity is observed with location of pile placed away from the crest of the slope. It is observed that, after distance of 5cm lateral capacity improvement is significantly reduced.

Further study is required to determine the lateral loading with considering the reinforcement effect.

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